DEVELOPMENT OF A NEW GENERATION STRATIFIED CHARGE ENGINE ON THE BASE OF ñMR-PROCESSò COMBUSTION MECHANISM

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ABSTRACT

Today, with the increasing seriousness of global warming, emission standards related with internal combustion engines continuously decrease the upper limits of exhaust gases emissions. CO_2, which is the most critical human-sourced greenhouse gas due to its contribution to global warming, will be limited to 100 ï 110 g / km by the year 2020. Decreasing the CO_2 emissions is possible only with the decrease of fuel consumption, and this can be done most effectively by operating the engine with stratified charge principle in which lean air-fuel composition (λ>1) is used at all working regimes. In this context, a stratified charge engine operated with ñMR-Processò - Two-Stage Combustion Mechanism, which is proposed in Azerbaijan Technical University (AzTU) and has been developing in cooperation of Warsaw Technical University (WTU), and ITU, is presented in order to achieve this goal. The development of a gasoline engine using stratified charge concept is emphasized. Moreover, CO_2 emission of a stratified charge engine is calculated by using a thermodynamic model. It is seen that the CO_2 emission of a vehicle with conventional gasoline engine is above 160 g / km, and can be decreased to 120 g / km by using stratified charge, considering that the vehicle is travelling at constant speeds of 60 and 90 km/hour.

Keywords: Spark ignition (SI) engine; NO_x and CO_2 emissions, Stratified Charge, ñMR-Processò

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1. Introduction

Nowadays, diesel fuels have been used widespread in automobiles, especially in Europe. The reasons of this dieselization are the fact that compression ignition, CI, or diesels are more economical than spark ignition, SI, engines and diesel fuels price is lower than that of gasoline. If it is taken into account that larger engines are mainly diesels, it is not difficult to estimate that delivery balances of petrol oil origin fuels will collapse due to this shift from gasoline to diesel fuels. As quantities of diesel and gasoline fuels from crude oil refinery are approximately the same, it can be estimated also that in near future the diesel fuel price will be higher than the price of gasoline. Consequently, a development of a new generation SI engine that can compete with CI engine is one of the more important subjects of the internal combustion, IC, innovation agenda. This importance is getting higher when it is considered that additionally to gasoline in the world IC engine fuel market there are production of biological and synthetic based light fuels as methanol, ethanol, biogasoline etc., liquefied petrol gas LPG, and compressed natural gas, CNG.

The biggest problem of todayǿs SI engines to be solved is the reduction of carbon dioxide, CO_2, exhaust gas emissions. In order to operate properly a conventional SI engine equipped with tree-way catalytic converter must be operated with a stoichiometric fuel/air mixture, or with excess air coefficient =1, but this leads to a high CO_2 emissions. According to the newer Kyoto Protocol, CO_2 emissions from transport and industry must be reduced 20% until 2020, thus from SI engines this reduction target is from 180-200 g/km to 100-110 g/km. When the power source of the of the automobile is only SI engine, most effective way to reach this emission reduction target is to apply stratified charge combustion principle by using lean mixtures with >1.4 at part-load regimes. Industrial applications of gasoline direct injection, GDI, from some of leading automobile manufacturers have not been so successful in reduction of CO_2 emissions. Last several years as result of cooperation between Istanbul Technical University and TUMOSAN Company successful results are obtained in converting tractor diesel engine into LPG and CNG fuel operation by using ñMR-Processò two-stage combustion mechanism as a type of the stratified charge combustion principle. A success and experience gained during this cooperation work leads to a development of an effective new generation stratified charge engines.

2. ñMR-Processò - Two-stage combustion mechanism

A stratified charged engine operating with ñMR-Processò - Two-Stage Combustion Mechanism is proposed in Azerbaijan Technical University and has been developing in cooperation of Warsaw University of Technology and Istanbul Technical University.

In Figure 1, scheme of the twin swirl CC (MR-2 CC) with two-stage combustion mechanism and examples of high-speed photographs from a physical model in Warsaw University of Technology are given [1, 2]. As a result of experimental investigations, it is found that swirl velocity must be between å 600 s^{-1} and å 1500 s^{-1}. As shown in this figure, CC looks like ñ8ò and is separated into two zones. While the first zone contains all the cycleõs fuel plus a half of the cycleõs air, thus fuel-rich mixture is formed with = 0.6é 0.9, the second zone contains the other half of this air. In these zones, the counter rotating swirling motion occurs during the intake and the compression strokes of the engine. The equality of rotational moments and speeds preserves these separate movements at all load regimes of the engine until the start of ignition initiated from the spark plug located at the rich mixture zone of the CC. During the first-stage combustion, by burning the rich mixture, incomplete combustion products (CO and H_2) are formed and then they are burned during the second-stage combustion. Burning of the charge in a swirl motion which does not cause detonation in the engine, permits its compression ratio to be raised up to optimal values = 12é 15. Realization of combustion in two stages also decreases CO and HC emissions. At the second stage, since CO and H_2 are burned very quickly, nitrogen cannot find enough time to be oxidized which leads to reduction of NO_x emissions. In view of the fact that in all engine operation regimes globally lean mixture can be burned, this proposed mechanism has a potential to reduce the fuel consumption, consequently to reduce the CO_2 exhaust emissions.

As the swirl motions occur during the intake stroke, the air-fuel mixture can be prepared in the outside of cylinders in the intake manifold of the engine. Therefore, this method can be applied very easily with current electronic injection systems.

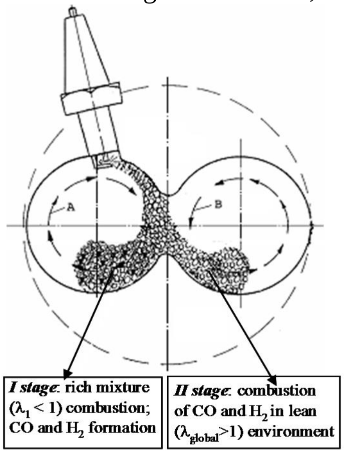

Figure 1. Two-stage combustion mechanism in twin swirl CC (MR-2 CC)

3. Theoretical calculations

Emission outputs of conventional and stratified charged engines are compared using a calculations of mathematical model of turbulent combustion process in SI internal combustion engine. Details of this model are given in the reference [3]. The CO_2 emission values of the conventional SI engine are taken as a reference value for the comparisons with the ones of the stratified engine. In the Table 1, modelõs results which are calculated for partial load operation at engine rotational frequency *n* = 2000 min^{-1} are given. Here, ( ) is the excess air ratio, ($_v$) is the volumetric efficiency, and ( ) values of stratified charged engine versions are higher than conventional ones due to the absence of a throttle valve. The values for compression ratios ( ) and excess air ratio ( ) are chosen such that the power output result for each stratified charged engine version simulation is equal to the power output value calculated for the conventional SI engine. For the partial load operation, CO_2 emission reduction can reach up to 19.2% with = 13. The reduction of CO_2 emission in partial loads is especially critical due to the fact that engines are generally operated in this mode such as road vehicles during in-city traffic conditions. The reduction of CO_2 emissions is mainly due to three factors: 1) lean fuel-air mixtures; stratified combustion, 2) higher volumetric efficiency due to the reduction of pumping losses at partial load conditions and 3) the improved thermal efficiency due to the higher engine compression ratios. This reduction can be enhanced by using higher compression ratios and higher stratification rates (excess air ratio). In practice, the use of high compression ratios is limited by the occurrence of detonation, and the use of very lean mixtures can lead to inappropriate conditions for the flame propagation.

Table 1. Reduction of CO_2 emission for partial load operation

Partial load	INPUTS			OUTPUTS		
n = 2000 min^{-1}	v			P_e, kW	b_e, g/kWh	Relative CO_2 reduction
Conventional	0.60	9.0	1.00		264	0 (reference)
		10.0	1.70	17.9	239	9.8 %
Stratified charge	0.95	11.5	1.80		224	14.8 %
		13.0	1.90		212	19.2 %

4. Engine tests

In order to investigate the effectiveness of the MR-2 CC a series of tests are conducted with one cylinder gasoline prototype engine (S/D = 92/92 mm) that is specially modified from real gasoline passenger car engine [2]. This single test engine was equipped and tested with two different cylinder heads. The first one is a conventional engine head and the second one is with a modified CC MR-2. Following two version tests are performed:

1. Conventional CC (compression ratio = 8.2); used fuel ï gasoline A-93, octane number of 93;

2. Modified MR-2 CC constructed in accordance to the scheme shown in Fig.1, compression ratio = 11.4, gasoline A-76, octane number of 76.

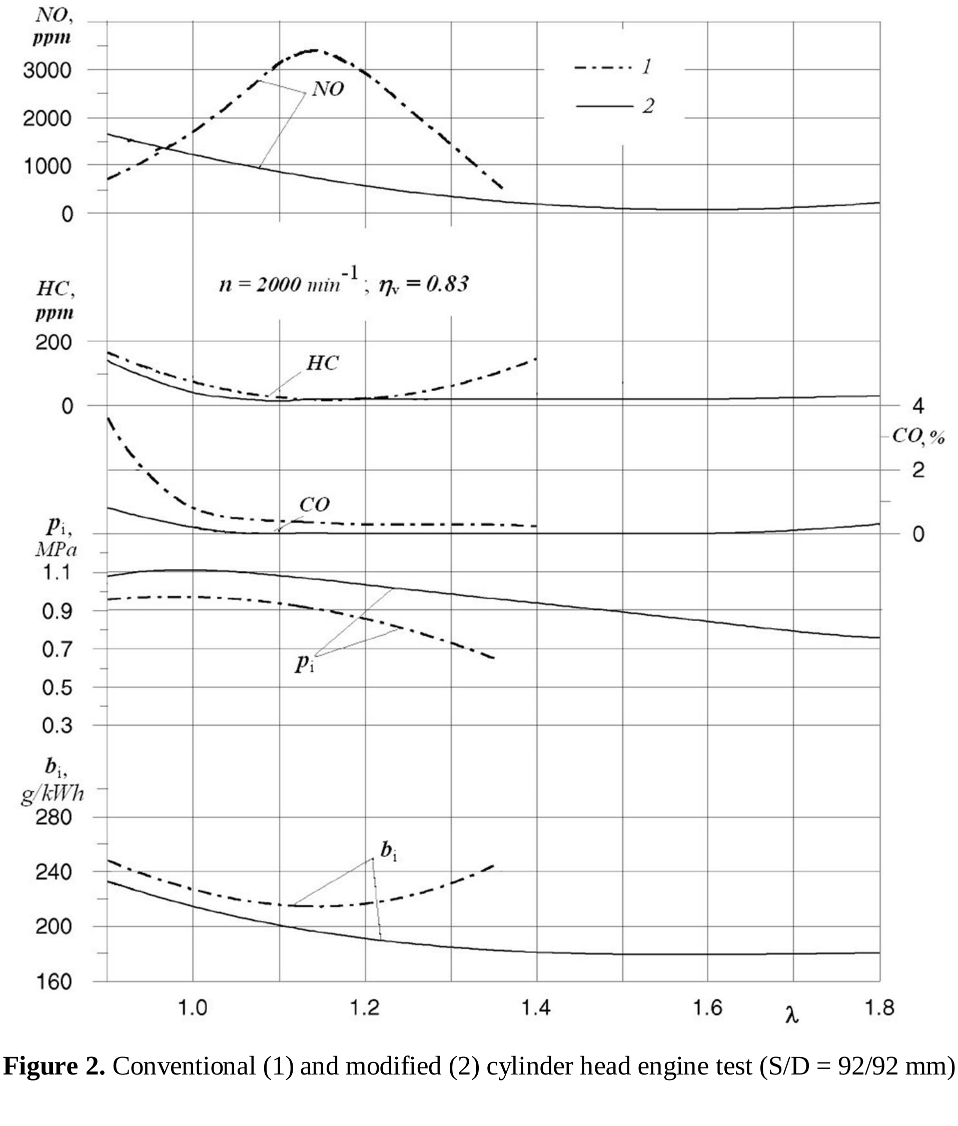

Figure 2. Conventional (1) and modified (2) cylinder head engine test (S/D = 92/92 mm) results.

In Figure 2, variations of NO, HC, CO, mean indicated pressure p_{mi} and specific fuel consumption b_i for these two version tests versus excess air ratio (λ) are shown. Both tests are conducted at full load, n = 2000 min^{-1}, and volumetric efficiency $_v$ = 0.83. These experiments have shown that two-stage combustion mechanism has high resistance to detonation. As seen in Fig. 2, the engine with conventional CC gives highest performance at =8,2 and with only higher octane gasoline (A-93). While, MR-2 CC allows engine to work without detonation at =11,4 using lower octane gasoline (A-76). Besides this combustion mechanism provides better cycle to cycle combustion stability at a wide range of excess air coefficient of the charge (and more). These properties of engine with MR-2 CC enable an increase in mean indicated pressure p_{mi} and specific fuel consumption b_i as well as a decrease in exhaust emissions (NO, CO, HC).

In addition to achieving high performance and efficiency with ñMR-Processò application for the 3 and 4 cylinder tractor diesel engines (S/D=115/104 mm) which are the production of TUMOSAN Engine and Tractor Industries, TUBITAK supported projects are held with cooperation with ITU in order to decrease the exhaust emissions to current standards. In the scope of these studies the LPG and CNG versions of the developed engines are targeted to be developed. In order to adopt 4 cylinder TUMOSAN diesel engine to work with LPG and CNG fuels, a cylinder head with 4 valves per cylinder (Figure 3.) and a piston with a compression ratio =14 having Twin Swirl MR-2 combustion chamber is designed and a few units are produced as first prototype.

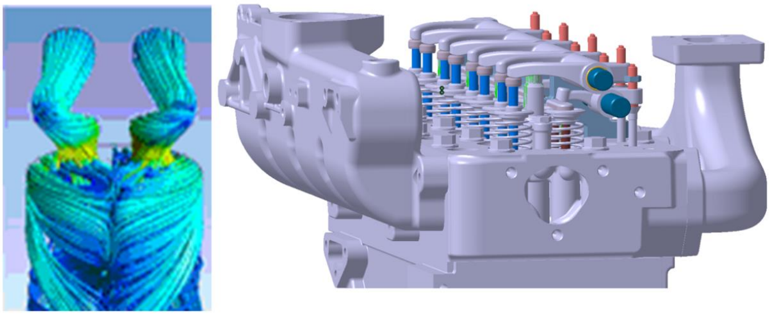

Figure 3. 3D figures of 16 valve cylinder head and intake ports of tractor engine which uses ñMR-Processò Combustion Mechanism.

The spark plug is inserted to the center of the cylinder where the twin swirls are tangent and the gas injector is inserted into one of the intake ports as. Injectors are adjusted to inject vaporized LPG (%50 Propane + %50 Butane) at the start of intake process with 3,0-3,5 bars.

The first prototype engine is tested at test bench of TUMOSAN R&D labs with 160 kW active dynamometer and RAW DIESEL Exhaust gas analysis system. In the experiments SMETEC (Germany) brand indicator measurement devices is used to measure in cylinder indicated parameter. With fist calibration test the optimum values for spark advance and excess air ratio are determined. Obtained test results are compared to Stage IIIA diesel engine which uses MR-1/V2 combustion chamber (detailed information about this engine is given in [4]) and evaluations are done.

In Figure 4. the comparison of indicator diagrams of LPG (=14) and diesel (=17) engine at same speed and load regimes (n=2500 *1/min*, p_{me}=0,67 *MPa*) are given. In the text below the figure engine parameter and emissions values are also compared. It is seen from the comparison of these values that, LPG engine provides the same power with a better efficiency (d_e=*0,37* compared to *0,39*) and less emissions (NO_x=539 *ppm* compared to 200 *ppm* and HC=416 *ppm* compared to 85 *ppm*).

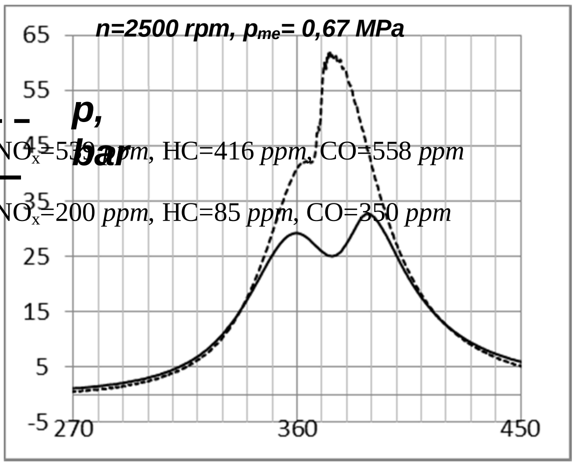

Figure 4. Comparison of Indicator Diagrams (full load *Pe*=75 *BG*)
Diesel: λ = 1,6, d_v=0,85, d_e=0,37
LPG: λ = 1,38, d_v=0,79, d_e=0,39

This positive result of the LPG engine can be seen from Figures 5. and 6. in the graphs of mean effective pressure versus (p_{me}) engine and emission parameters in the maximum torque speed regime (n=1500 *1/min*). As can be seen from Figure 5. when the engine works with LPG fuel the maximum value of mean effective pressure (torque) reaches p_{me}=0,85 *MPa* even it is p_{me}=0,676 *MPa* in the diesel engine meaning the torque or the power of the engine when working with LPG is increased by %25. But the NO_x emissions are increased unacceptably when p_{me}=0,85 *MPa* is achieved in the value of =*1,1* excess air ratio (this value of ' is not valid for diesel engines due to excessive smoke) (Figure 5.). Thus it is needed to limit the value of maximum richness value as =1,36 of the fuel air mixture. In this situation even the maximum value of mean effective pressure is decreased to p_{me}=0,735 *MPa*, there is a %9 rise in the torque compared to diesel engine. In this situation, in all load regimes while LPG engine works more efficient than diesel engine (higher $_e$), it creates less pollutant emissions (NO_x, HC and CO).

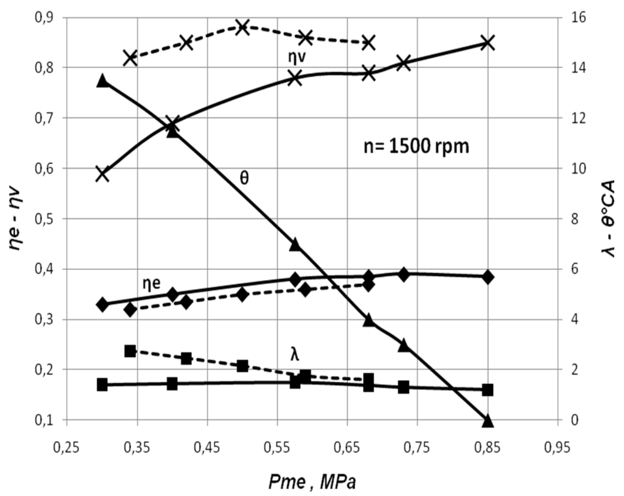

Figure 5. Comparison of engine parameters
(LPG, Diesel).

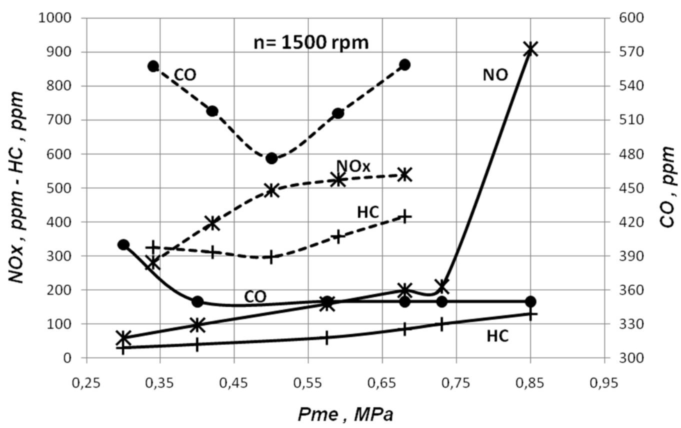

Figure 5. Comparison of exhaust gas emission values
(LPG, Diesel).

As can be seen from Figure 6. when compared to diesel engine which meets Stage IIIA standards, emission values of LPG engine can meet Stage IIIB even Stage IV undoubtedly considering the PM emissions are near zero.

Thus, by applying ñMR-Processò combustion mechanism it is possible to convert diesel engine to LPG fuel with high performance and efficiency and meet current emission standards without using extra emission treatment devices. These results show that by using ñMR-Processò combustion mechanism there is an effective alternative way to develop stratified charged engine which is economical as diesel engines, superior in exhaust emissions than diesel engines, and powerful as gasoline engines.

5. CONCLUSIONS

By using MR-2 CC two-stage mechanism the engine:

1. When compared with conventional spark-ignition engine, fuel consumption and CO_2 can be reduced approximately 20% at the same power with compression ratio = 12-15 and excess air ratio ≥ 1,35.

2. When compared with conventional diesel engine, effective power can be increased by ~10%, fuel economy approximately by 9% and CO, HC, NO_x emissions two-three times can be reduced at the same compression ratio = 14 - 17 and excess air ratio ≥1,42.

3. On the base of these results by applying ñMR-Processò Combustion Mechanism it is possible to develop effective **New Generation Stratified Charge Engines.**

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